involving fertility and plant nutrition are finally solved, I am inclined to think this is the only means whereby we can hope for success. At least the information derived in this way is more apt to bring us to the desired state of knowledge than our present independent attitude. "The sciences gain by mutual support," wrote Pasteur. Certainly it is not by an arrogant assumption to one's self that his particular science is the "be all and end all" of human endeavor, that we shall gain any notion of what is really happening in the soil and what it all means!

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PLANT FOOD IN RELATION TO SOIL FERTILITY[1]

I take it that the only justification for me to review the subject of plant food in relation to soil fertility or crop production is the fact that recent publications from the federal Bureau of Soils have strongly affirmed that there is no necessity of applying plant food in the restoration and maintenance of soil fertility. Two principal questions are raised: First, Does plant food applied increase crop yields in harmony with recognized soil deficiencies and crop requirements? Second, Will the rotation of crops maintain the productive power of the soil by avoiding injury from possible toxic excreta from plant roots? I shall try to present facts and data and exact quotations rather than my own opinions concerning these questions of such fundamental importance in relation to systems of permanent agriculture.

In 1804 DeSaussure, the French scientist, first gave to the world a correct and almost complete statement concerning the sources of the food of plants, including not only the confirmation of Sénébier's discovery of the fixation of carbon in the formation of carbohydrates, but also the evidence of plant requirements for the essential mineral elements secured from the soil.

Sir Humphry Davy and Baron von Liebig did much to popularize this information during the following half century; and they were followed by Lawes and Gilbert, whose extensive and long-continued investigations furnished the needed proof that the soil must furnish nitrogen as well as the mineral elements; and finally, only twenty-five years ago, Hellriegel discovered the symbiotic relationship between legumes and bacteria which gives access to the inexhaustible supply of atmospheric nitrogen for soil enrichment.

Briefly, it might be said that for nearly a century the world of science has accepted and taught, and the world of advanced agricultural methods has practised, the doctrine that soil fertility maintenance and soil enrichment require the restoration or addition of plant food, including particularly phosphorus and nitrogen, which are most likely to become deficient in normal soils, potassium where needed, and sometimes lime or limestone, which always supplies calcium, and magnesium as well if dolomitic limestone be used. Of the other five essential elements, carbon and oxygen are secured from the carbon dioxid of the air, hydrogen from water, and iron from the inexhaustible supply in the soil; while the sulfur brought to the soil in rain and otherwise from the atmospheric supply, resulting from combustion and decomposition of sulfur-bearing materials, supplemented by the soil's supply and by that returned in crop residues, appears to be sufficient to meet the plant requirements and the loss by leaching.

After nearly a century of the increasing

[1] Presented at the Symposium on Soils at the Washington meeting of the American Association for the Advancement of Science.

agricultural practise of this doctrine on much of the farm land of Germany, France, Belgium, Holland, Denmark and the British Isles, those countries have approximately doubled their average acre-yields. The ten-year average yield of wheat in the United States is 14 bushels per acre, while that in Europe has gone up to 29 bushels in Germany, to 33 bushels in Great Britain, and to more than 40 bushels per acre in Denmark. The annual application of phosphorus even to the soils of Italy has already become greater than the phosphorus content of all the crops removed. The exportation of our highest grade phosphate rock from the United States to Europe now exceeds a million tons a year, carrying away from our own country twice as much phosphorus as is required for the annual wheat crops of all the states, and millions of acres of farm land in our own eastern states have already been agriculturally abandoned, because of depleted fertility and reduced productive power; so that it is now impossible for our congressmen to enter the capital of the United States from any direction without passing abandoned farms.

Ultimate analysis has shown that the most common loam soil of southern Maryland,[2] almost adjoining the District of Columbia, contains only 160 pounds of phosphorus, 1,000 pounds of calcium and about 900 pounds of nitrogen in two million pounds of surface soil, corresponding approximately to an acre of land 6⅔ inches deep. The clover crops harvested from the rich garden soil at Rothamsted in eight consecutive years removed more phosphorus and calcium from the soil than the total amounts contained in the plowed soil of this worn-out Maryland land, whose total nitrogen content is also less than would be required for seven such crops of corn as we harvest on good land in the central west, which, however, contains ten times as much of these plant foods as the depleted Maryland soil.

During the last ten years our population increased 21 per cent., the same as during the preceding decade, while the acreage of farm lands increased only 5 per cent., and the federal government reports all future possible increase in farm land at only 9 per cent. of our present acreage.

Average crop yields for four ten-year periods are now reported by the United States Department of Agriculture. A comparison of two twenty-year averages shows increased acre-yields of 1 bushel for wheat and ½ bushel for rye, while the yield of corn has decreased 1½ bushels and the yield of potatoes has decreased 7 bushels per acre, by twenty-year averages. These crops represent our greatest sources of human food, even our supply of meat being largely dependent upon the corn crop. Less than twenty-year averages are not trustworthy for a consideration of any small increase or decrease in yield per acre. It should be noted that during the last forty years vast areas of virgin wheat land have been put under cultivation, including the Dakotas, which now produce more wheat than all the states east of the Mississippi, save only Indiana and Illinois.

A comparison of the last five years with the average of the five years ending with 1900 shows that our wheat exports decreased during the decade from 198 million to 116 million bushels, and that our corn exports decreased from 193 million to 57 million bushels.

Thus we have fed our increasing population not by increasing our acre-yields, but by a slight increase in the acreage of

[2] See "Leonardtown Loam," Bureau of Soils Bulletin 54, and "Field Operations of the Bureau of Soils" in Reports for 1900 and 1901; or see pages 138 to 142 of "Soil Fertility and Permanent Agriculture," Ginn & Company, Boston.

farm land, and by a large decrease in our exportation of food stuffs; and the fact must be plain that before another decade shall have passed we shall reach the practical limit of our relief in both of these directions.

Indeed, a most common subject already discussed in the press and investigated by national, state and city authorities during the last three or four years is the high cost of plain living.

With these facts and statistics before us, let us consider the actual results secured from field and laboratory investigations:

Where wheat has been grown every year since 1844 on Broadbalk Field at Rothamsted, England, the average yield for fifty-five years has been 12.9 bushels per acre on unfertilized land, 35.5 bushels where heavy annual applications of farm manure have been made, and 37.1 bushels per acre where slightly less plant food has been applied in commercial form.

Barley grown every year on Hoos Field at Rothamsted has produced, for the same fifty-five years, an average yield of 14.8 bushels on unfertilized land, 47.7 bushels with farm manure and 43.9 bushels where much less plant food was applied in commercial form.

Potatoes grown for twenty-six consecutive years, also on Hoos Field at Rothamsted, produced, as an average, 51 bushels per acre on unfertilized land, 178 bushels where farm manure was used (reinforced with acid phosphate during the first seven years), and 203 bushels where plant food was applied in commercial form. The first year of this investigation the unfertilized land produced 144 bushels, land receiving farm manure alone produced 159 bushels and land fertilized with commercial plant food produced 328 bushels per acre.

Director A. D. Hall, of the Rothamsted Experiment Station, makes the following statement on pages 95 and 96 of his book on "The Rothamsted Experiments":

> On the plots receiving farmyard manure, and even on those receiving only a complete artificial manure, the crop was maintained in favorable seasons. No falling-off was observed which could be attributed to the land having become "sick" through the continuous growth of the same crop, or through the accumulation of disease in the soil.

In commenting upon these same experiments, Milton Whitney, Chief of the United States Bureau of Soils, makes the following statement in Farmers' Bulletin No. 257, page 14:

> One of the most interesting instances going to show that toxic substances are formed and that what is poisonous to one crop is not necessarily poisonous or injurious to another is a series of experiments of Lawes and Gilbert—the growing of potatoes for about fifteen years on the same field. At the end of this period they got the soil into a condition in which it would not grow potatoes at all. The soil was exhausted, and under the older ideas it was necessarily deficient in some plant food. It seems strange that, under our old ideas of soil fertility, if the soil became exhausted for potatoes, it should grow any other crop, because the usual analysis shows the same constituents present in all of our plants, not in the same proportion, but all are present and all necessary, so far as we know. This field was planted in barley, and on this experimental plot that had ceased to grow potatoes they got 75 bushels of barley.

If, now, we turn to the actual records of the Rothamsted experiments we find that the first crop of barley grown after twenty-six years of potatoes was 33.2 bushels per acre on unfertilized land, only 24.8 bushels where minerals alone had been used and the soil depleted of nitrogen by the potato crops, 67 bushels per acre where minerals and nitrogen had been used, and 72.4 bushels where farm manure had been applied for twenty-six years. We also find in strict harmony with Director Hall's statement, that the largest average yield of potatoes from the farm manure plots (3

and 4), either for one year or for five years, was secured after potatoes had been grown on the same land for more than fifteen years.

On permanent meadow land at Rothamsted, the average yield of hay for fifty years was 1¼ tons per acre on unfertilized land, and more than 4 tons per acre on land heavily fertilized with commercial plant food. During the last ten years of this fifty-year period the unfertilized land has produced an average yield of 1,863 pounds of hay, while the fertilized land has produced 8,490 pounds per acre.

On Barn Field at Rothamsted, mangels were grown for thirty years. The average yield per acre was 4¼ tons on unfertilized land, 19½ tons where farm manure had been applied, and 29 tons per acre where the farm manure had been reinforced with nitrogen and phosphorus in commercial form.

In 1902 the University of Illinois began a series of experiments on the common corn-belt prairie land in McLean County, on a field which had grown no wheat for thirty-two years. We first grew wheat in 1905. Four plots not receiving phosphorus produced, respectively, 28.8 bushels, 30.5 bushels, 33.2 bushels and 29.5 bushels of wheat per acre; while four other plots which differed from these only by the addition of phosphorus, at the rate of 25 pounds of that element in 200 pounds of steamed bone meal per acre per annum, produced 39.2 bushels, 50.9 bushels, 37.8 bushels and 51.9 bushels, respectively, per acre. Six years later wheat was again grown on this land, when the four plots not receiving phosphorus produced, respectively, 22.5 bushels, 25.6 bushels, 21.7 bushels and 27.3 bushels per acre, and the other four plots, which differ from these in treatment only by the phosphorus applied during the ten years, produced 57.6 bushels, 60.2 bushels, 54.0 bushels and 60.4 bushels, respectively, of wheat per acre, this being the second crop of wheat grown on this land in forty years.

This most common prairie land of the Illinois corn belt contains 600 pounds of phosphorus and 18,000 pounds of potassium per million of surface soil, while one million pounds of the subsoil contains 450 pounds of phosphorus and 27,000 pounds of potassium. This is the type of soil on which, as an average of four different tests each year under four different conditions of soil treatment, the addition of phosphorus produced an increase in yield per acre of 9.6 bushels of corn in 1902, of 17.8 bushels of corn in 1903, of 14.8 bushels of oats in 1904, of 14.4 bushels of wheat in 1905, of 1.46 tons of clover[3] in 1906, of 18.8 bushels of corn in 1907, of 17.3 bushels of corn in 1908, of 15.2 bushels of oats in 1909, of 2.56 tons of clover[3] in 1910 and an average increase of 33.8 bushels of wheat per acre in 1911.

As an average of four similar tests during the ten years, applications of potassium (costing the same as the phosphorus) increased the yield of corn by 3.1 bushels, decreased the yield of oats by 2.3 bushels, decreased the yield of clover by 70 pounds per acre and increased the yield of wheat by 0.1 bushel per acre, these being the general average results from four years of corn and from two years each of oats, clover and wheat.

If now we turn to the extensive peaty swamp soil of northern and north-central Illinois, we find by analysis that it contains in one million pounds of the surface soil 1,960 pounds of phosphorus and 2,930 pounds of potassium, or more than three times as much phosphorus and less than one sixth as much potassium as the com-

[3] Average of two tests (see Illinois Soil Report No. 2, pp. 17, 39).

mon prairie. We also find that, as an average of triplicate tests each year, potassium increased the yield of corn per acre by 20.7 bushels in 1902, by 23.5 bushels in 1903, by 29.0 bushels in 1904 and by 36.8 bushels in 1905; while the addition of phosphorus produced a decrease of 0.1 bushel in 1902 and an increase of 0.9 bushel in 1903, of 3.9 bushels[4] in 1904 and of 0.3 bushel in 1905.

As an average of the results from twenty plots of unfertilized land in the Pennsylvania rotation experiments with corn, oats, wheat and hay (clover and timothy mixed), the crop values in two consecutive twelve-year periods decreased by 26 per cent.; while, as an average of the twenty-four years, the crop values were increased 62 per cent. by farm manure and 65 per cent. with commercial plant food, as compared with the results from unfertilized land.

The records from the Agdell rotation field at Rothamsted show that as an average of the turnips, barley, clover (or beans) and wheat the yield decreased on unfertilized land by 42 per cent. measured by the results from two consecutive thirty-two-year periods; and, if we span a sixty-year period, we find that the yield of turnips on unfertilized land was 10 tons per acre in 1848 and less than ½ ton in 1908; that the barley yielded 46.5 bushels in 1849 and only 10 bushels per acre in 1909; the clover produced 2.8 tons in 1850 and less than 1 ton per acre in 1910; while the wheat following clover produced 39.7 bushels in 1851 and 24.5 bushels in 1911.

The application of plant food (for the turnip crop only) in the same rotation over a period of sixty-four years increased the average yield of turnips from 1¼ tons to 17½ tons per acre, increased the yield of the barley following from 24.4 to 38.5 bushels, then increased the average yield of legumes from 1,945 pounds to 4,413, and increased the yield of wheat after legumes from 25 to 34.8 bushels, as compared with the unfertilized land.

If, again, we span the sixty years, we find that on the fertilized land the yield of turnips was 12½ tons in 1848 and 17½ tons in 1908; that barley produced 35.9 bushels in 1849 and 33.4 bushels in 1909; that clover produced 3½ tons in 1850 and 4½ tons in 1910; while wheat yielded 30.3 bushels in 1851 and 38 bushels per acre in 1911.

Thus, the records show that during the last four years, following a sixty-year period, the plant food applied has increased the yield of wheat by 55 per cent., increased the barley by 234 per cent. and the clover by 340 per cent.; while the yield of turnips on the fertilized land was 49 times as great as on the unfertilized land.

With these facts in mind we may well consider the following statements from Whitney in Farmers' Bulletin 257:

> Apparently, these small amounts of fertilizers we add to the soil have their effect upon these toxic substances and render the soil sweet and more healthful for growing plants. We believe it is through this means that our fertilizers act rather than through the supplying of food to the plant. (Page 20.)
>
> There is another way in which the fertility of the soil can be maintained, viz., by arranging a system of rotation and growing each year a crop that is not injured by the excreta of the preceding crop; then when the time comes around for the first crop to be planted again the soil has had ample time to dispose of the sewerage resulting from the growth of the plant two or three years before. . . . Barley will follow potatoes in the Rothamsted experiments after the potatoes have grown so long that the soil will not produce potatoes. The barley grows unaffected by the excreta of the potatoes, another crop follows the barley, and the soil is then in condition to grow potatoes again.

[4] Irregular insect injury in 1904 (see Illinois Bulletin 123, pp. 251, 252).

In other experiments of Lawes and Gilbert they have maintained for fifty years a yield of about 30 bushels of wheat continuously on the same soil where a complete fertilizer has been used. They have seen their yield go down where wheat followed wheat without fertilizer for fifty years in succession from 30 bushels to 12 bushels, which is what they are now getting annually from their unfertilized wheat plot. With a rotation of crops without fertilizers they have also maintained their yield for fifty years at 30 bushels, so that the effect of rotation has in such case been identical with that of fertilization. (Pages 21, 22.)

If we turn to the Rothamsted data, we find that the first recorded yield of wheat on the unfertilized plot on Broadbalk Field was not 30 bushels, but only 15 bushels; that the average of the first eight years was 17.4 bushels; that the best fertilized plot on the same field has averaged not 30 bushels, but 37.1 bushels for fifty-five years; that, as stated above, the wheat grown in rotation, following a leguminous crop, has averaged not 30 bushels, but 25 bushels on unfertilized land, and 34.8 bushels where fertilizers are applied for turnips three years before.

The following pertinent quotations are from Whitney and Cameron in Bureau of Soils Bulletin 22:

In England and Scotland it is customary to make an allowance to tenants giving up their farms for the unused fertilizers applied in previous seasons. The basis of this is usually taken at 30 to 50 per cent. for the first year, and at 10 to 20 per cent. for the second year after application; but, in the experience of this bureau there is no such apparent continuous effect of fertilizers on the chemical constitution of the soil. (Page 59.)

It appears further that practically all soils contain sufficient plant food for good crop yield; that this supply will be indefinitely maintained. (Page 64.)

In Bureau of Soils Bulletin 55, by Whitney, entitled "Soils of the United States," issued in 1909, we find under the heading "Permanency of Soil Fertility as a National Asset" the following summarized statements:

The soil is the one indestructible, immutable asset that the nation possesses. It is the one resource that can not be exhausted; that can not be used up. (Page 66.)

From the modern conception of the nature and purpose of the soil it is evident that it can not wear out, that so far as the mineral food is concerned it will continue automatically to supply adequate quantities of the mineral plant food for crops. (Page 79.)

As a national asset the soil is safe as a means of feeding mankind for untold ages to come. (Page 80.)

As stated in the beginning, I have not planned to discuss the subject of plant food in relation to soil fertility; but I felt it a duty as well as an honor to be permitted to accept a place on your program; and I have placed before you some most important and trustworthy data bearing upon the question. I have presented some statistics for consideration in connection with the gravest problem which now confronts America; namely, the problem of restoring American soil and of maintaining American prosperity. I have quoted accurately and fairly from the teachings of Whitney and Cameron; and I also submit for your information the following quotation from Director A. D. Hall, of Rothamsted:

I can not agree with Professor Whitney's reading of the results on the Agdell field in the least. The figures he quotes for wheat are hardly justifiable as approximations, and are in spirit contrary to the general tenor of the particular experiment. . . . In my opinion the results on the Agdell rotation field are directly contrary to Professor Whitney's idea that rotation can do the work of fertilizers. (From Report of the Committee of Seven, appointed by the Association of Official Agricultural Chemists "to consider in detail the questions raised," published in full in Circular 123 of the University of Illinois Agricultural Experiment Station.)

A thousand additional proofs of the practical value and of the evident necessity of supplying plant food in systems of

permanent agriculture could easily be cited.

All long-continued investigations and, likewise, all practical agricultural experience show that great reduction in crop yields ultimately occurs unless plant food is restored to the soil; and, as a rule, the chemical composition of normal soil is an exceedingly valuable guide in determining the kinds of material which should be supplied in practical systems of soil enrichment and preservation.

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THE FIFTH INTERNATIONAL CONGRESS OF MATHEMATICIANS

Once every four years the mathematicians of the world meet together to discuss the new discoveries made in the various branches of their science, to review the work accomplished during the past quadrennial period, to listen to mathematical papers and to become acquainted with one another. The fifth International Congress of Mathematicians was held at Cambridge University, August 21 to 28, 1912, at the invitation of the Cambridge Philosophical Society. The four former congresses were Zurich, 1897; Paris, 1900; Heidelberg, 1904; Rome, 1908. During the World's Fair at Chicago in 1893, a similar international gathering of mathematicians was held, but this meeting is not usually included in the list of meetings of the International Congress.

The opening meeting was devoted to welcoming addresses by the president of the Cambridge Philosophical Society, Sir George Darwin, and the vice-chancellor of the university, Mr. R. F. Scott. Sir George Darwin emphasized the great trend towards specialization among modern mathematicians and referred to the great loss sustained by mathematics in the recent death of Henri Poincaré, who was probably the one man competent to appreciate mathematical research in all its diverse branches. Darwin referred to the Cambridge School of Applied Mathematicians in the last century, mentioning Airy, Adams, Maxwell, Stokes, Kelvin and Rayleigh, and analyzed the characteristic differences in the mental attitudes of the pure and applied mathematician.

The officers of the congress were elected as follows: *President,* Sir George Darwin; *Vice-presidents,* W. von Dyck, L. Fejér, R. Fujisawa, J. Hadamard, J. L. W. V. Jensen, P. A. MacMahon, G. Mitlag-Leffler, E. H. Moore, F. Rudio, P. H. Schoute, M. S. Smoluchowski, V. A. Steklov, V. Volterra; *General Secretaries,* E. W. Hobson and A. E. H. Love.

The congress was organized in four sections devoted, respectively, to arithmetic-algebra-analysis, geometry, applied mathematics and philosophical, historical and didactical questions. The section of applied mathematics was divided into two, one for mathematical physics and astronomy, the other for economics and statistics. This was done also in the case of the fourth section, one section taking up philosophy and history, the other didactics. The international committee having charge of the program appointed the first chairmen of the sections, each of whom gave a short introductory address. The other chairmen were appointed by the sections from day to day.

Section I. Arithmetic, Algebra, Analysis.—The first meeting was presided over by Professor E. B. Elliott, who in his opening address defended the British mathematician from the attacks of those who have said he is too self-centered and cared little for the furtherance of mathematical thought. In the five meetings of this section 28 papers were offered and open for discussion. Many of the papers dealt with that part of the field of analysis which centers about the integral equation. The chairmen for the meetings after the first were Professors E. Landau, E. Borel, E. H. Moore, H. von Koch.

Section II. Geometry.—The chairman of the first meeting, Dr. H. P. Baker, gave a brief survey of the present state of the theory of surfaces and extensions to space of more than three dimensions, and gave reasons for his belief that geometers were now on the threshold of many new discoveries through the